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NATIONAL POLAR-ORBITING OPERATIONAL ENVIRONMENTAL SATELLITE SYSTEM (NPOESS) PREPARATORY PROJECT (NPP)

ORBITAL DEBRIS ASSESSMENT

Code 429

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GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

INTEGRATED PROGRAM OFFICE
SILVER SPRING, MARYLAND

NPP ORBITAL DEBRIS ASSESSMENT

January 13, 2005

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NPP Orbital Debris Assessment

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Executive Summary

An Orbital Debris Assessment has been conducted for the National Polar-Orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP) Observatory in accordance with NASA Policy Directive NPD 8710.3A, "NASA Policy for Limiting Orbital Debris Generation" and NASA Safety Standard (NSS) 1740.14, "Guidelines and Assessment Procedures for Limiting Orbital Debris". The assessment concluded that the intent of all the applicable guidelines in NSS 1740.14 is met for the NPP mission. The highlights of the NPP Project self-assessment are contained in the table following this summary.

The NPP baseline calls for the spacecraft to use the resources of the on-board propulsion system to perform a controlled reentry to safe ocean disposal as soon as practical following termination of the mission. The decision to design NPP for controlled reentry was based on the results of orbital debris analysis performed in conjunction with the Johnson Space Center (JSC), Orbital Debris Program Office. This analysis concluded that the total NPP debris surviving an uncontrolled reentry would result in a human casualty risk of 1: 2,472 for a 2015 reentry (optimistic assumption), which is well in excess of the 1:10,000 casualty risk threshold currently deemed acceptable. Note this casualty threshold risk was computed considering only surviving debris with kinetic energy at impact of greater than 15 J as recommended by JSC for an uncontrolled reentry assumed to occur in 2015. Section 7.0 of this report contains a summary of the casualty risks for more severe kinetic energy and year of reentry assumptions. Under no conditions could NPP be shown to meet the 1: 10,000 guideline.

The NPP observatory is based on the Ball Aerospace BCP2000 catalog bus with specific modifications to support NPP mission unique requirements. The spacecraft design for controlled reentry will employ traditional single fault tolerant design practices. Spacecraft component probability analysis determined that the probability of success (Ps) for a controlled reentry performed at 5 years (the spacecraft design life) would be 0.98. While lower than the current guideline standard (Ps of .99), the NPP Project surmised that the additional design and operational complexity of increasing functionality to improve the Ps would have significant Project cost and schedule impacts, while potentially adding more risk than would be retired. While no formal cost-design analysis was performed on increasing Ps, the conclusion is consistent with design modifications to catalogue busses such as NPP. It is also understood that Code Q is currently considering changes to the guidelines to bring the Ps threshold in line with single point failure designs such as NPP.

Table X-X. NPP Project Self-Assessment

Guideline	Compliant	Non-Compliant	N/A	Comments
3-1.a	☒	☐	☐	**Debris released passing through LEO – 25-year maximum lifetime.** NPP observatory releases no debris during normal operations.
3-1.b	☒	☐	☐	**Debris released passing through LEO – 100-year total object time product.** NPP observatory releases no debris during normal operations.
3-2	☐	☐	☒	**Debris released passing through GEO** – NA. NPP observatory operates in LEO.
4-1	☒	☐	☐	**Limit the risk from accidental explosion during deployments and mission operations:** No credible single point failure from internal causes will cause explosion of the batteries or propulsion system during nominal mission operations. As NPP will deorbit as soon as practical after mission termination concerns over extended mission lifetime are not applicable.
4-2	☒	☐	☐	**Limit the risk from accidental explosion following mission operations:** NPP will undergo controlled reentry for safe ocean disposal as soon as practical after mission termination. Passivation is not required.
4-3	☐	☐	☒	**Limit the long-term risk from planned breakups** – NA, NPP has no planned test explosions, collisions or breakups while on orbit.
4-4	☐	☐	☒	**Limit the short-term risk from planned breakups** – NA, NPP has no planned test explosions, collisions or breakups while on orbit.
4-5	☐	☐	☒	**Limit the risk from planned breakups during reentry** – NA, NPP has no planned test explosions, collisions or breakups during deorbit.
5-1	☒	☐	☐	**Limit debris generated by collisions with large objects:** The probability of a NPP large object collision was calculated to be $8.6x10^{-4}$. This is within the guideline number of $1x10^{-3}$. (See Section 5)
5-2	☒	☐	☐	**Limit debris generated by collisions with small objects**: The probability of a NPP small object collision was computed to be within the guideline number of $1x10^{-2}$ for both the battery and propellant tank. (See Section 5)
6-1.a	☒	☐	☐	**Disposal of spacecraft structures passing through LEO – atmospheric reentry option.** NPP will undergo controlled reentry to safe ocean disposal as soon as practical following mission termination.
6-1.b	☐	☐	☒	**Disposal of spacecraft structures passing through LEO –storage orbit option.** NA.
6-1.c	☐	☐	☒	**Disposal of spacecraft structures passing through LEO –direct retrieval option.** NA
6-2.	☐	☐	☒	**Disposal for spacecraft structures near GEO.** NA
6-3	☐	☐	☒	**Disposal of spacecraft structure between LEO and GEO**. NA, NPP will be reentered for disposal.
6.4	☐	☒	☐	**Reliability of post-mission disposal** – NPP probability of success for controlled reentry at 5 years (required mission life) is .98 versus the guideline of .99. The Ps of .98 is consistent with single fault tolerant designs, additional functionality to improve the Ps was considered but determined to be non-cost effective and add more Project risk.
7-1	☒	☐	☐	**Limit the risk of human casualty –spacecraft reentry.** NPP will perform a controlled reentry to safe ocean disposal as soon as practical following science mission termination. ORSAT analysis indicates that the casualty risk associated with an uncontrolled NPP reentry would be between1: 2,500 and 1:2,100 depending on the year of reentry.
7-1	☐	☒	☐	**Limit the risk of human casualty –Launch vehicle reentry.** Delta second stage reentry casualty area exceeds guideline. Not reported herein.

1.0 BACKGROUND ON PROGRAM AND PROGRAM MANAGEMENT

1.1 Mission Description

The National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP) is a joint mission being formulated by National Aeronautics and Space Administration (NASA) and the NPOESS Integrated Program Office (IPO). The NPP is a bridge between the NASA Earth Observing System (EOS) program and NPOESS.

The NPP instrument complement includes: Visible-Infrared Imager Radiometer Suite (VIIRS), Advanced Technology Microwave Sounder (ATMS), Cross-Track Infrared Sounder (CrIS), and the Ozone Mapping and Profiling System (OMPS). The spacecraft bus is based on the Ball Aerospace and Technology Corporation BCP2000 Rapid Spacecraft Development Office (RSDO) catalog bus.

NPP is scheduled for launch in October of 2006. Launch will be via a Delta-II launch vehicle from Vandenberg Air Force Base. The nominal mission duration is five years. The orbit is 824 km altitude, sun synchronous (inclination =98.7 deg), with a 10:30 AM descending node. The orbit ground track will be controlled to repeat every 16 days to within 20 km.

More detailed and current mission information is available on the NPP Project's regularly updated website, http://jointmission.gsfc.nasa.gov/.

1.2 Program Objectives

NPP is a dual objective mission, seeking to provide continuity of climate data measurements for NASA and to support risk reduction for the NPOESS IPO. For NASA, NPP is part of the EOS program, providing extended observations for key sustained measurements identified in the EOS Science Plan. For the IPO, NPP provides an opportunity to demonstrate and validate new instruments, algorithms, and data distribution and processing capabilities prior to the first NPOESS flight. All of the NPP instruments are to be flown on NPOESS missions.

1.3 Program Schedule

NPP is scheduled for launch in October of 2006. The Spacecraft Critical Design Review was held in June of 2003. Other schedule details can be found on the project website identified above.

1.4 Responsible Program Manager

Ken Schwer is the NASA Goddard Space Flight Center NPP Project Manager. Contact information as well as the NPP IPO organization chart can be found at the website identified above.

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2.0 DESCRIPTION OF DESIGN AND OPERATIONS FACTORS

2.1 Hardware

2.1.1 Physical Description of Main Structure

The NPP spacecraft is based on the Ball BCP2000 commercial spacecraft bus modified to meet the NPP mission unique requirements. Several views of the NPP spacecraft are shown in Figure 2-1a & b. The spacecraft utilizes a panel-post construction system based on four aluminum corner posts. Aluminum honeycomb-core panels form the sidewalls and all decks. The nadir deck and corner posts provide the structural support to the five payloads. The propulsion deck provides mounting and structural support for the eight 22 N (five lb) hydrazine thrusters. The Delta separation system is mounted below the propulsion deck. The solar array is a deployable single wing consisting of three panels, with an area of 13.75 m^2 . The solar array structure is composed of aluminum honeycomb with graphite/epoxy facesheets. The spacecraft will fly with the nadir deck towards the earth. The yaw angle will remain constant, and the solar array will be pitched to maximize power generation.

2.1.2 Description of Surfaces/Materials Exposed to Space

Most of the spacecraft is covered with multi-layer insulation (MLI). MLI is composed of ten layers each of alternating layers of aluminized Mylar and polyester netting, between top and bottom layers of aluminized Kapton. The corner posts are used as thermal radiators, as is the outside of the battery. Radiators are covered with silver Teflon tape. The sunward side of the solar panel is covered with solar cells; the backside is painted white.

2.1.3 Description of Spacecraft Components Most Sensitive to Debris Impact

Previous debris analyses indicate that the primary debris hazard to a spacecraft is posed to those components facing the velocity direction. The debris flux from particles less than 1 mm in size in both circular and elliptical orbits shows a distinct directional distribution; peaks are a few tens of degrees from the velocity direction. For larger debris particles, the debris in circular orbits tend to be much more important than that in elliptical orbits.

The NPP spacecraft components which are most more susceptible to debris hazard are the MLI insulation and both sides of the solar panel. The MLI insulation will experience some erosion and degradation due to small debris impacts, particularly in the velocity direction. The thermal design is sufficiently robust to compensate for this degradation. Impacts of small debris will also cause degradation of the solar cells; such degradation is accounted for in the model of the end of life power system performance, at which time the power generation margin is projected to be about 15%. Small debris will have little if any significant effect on the backside of the solar panel.

2.1.4 Description and Location of Pressurized Volumes

The NPP spacecraft contains two pressurized systems: the battery assembly and the propulsion system. The propulsion system is described in the next section. NPP will carry two batteries. Each has a capacity of 85 A.hr NiH and consists of 22 pressurized cells. The cell operating pressure is 1135 pounds per square inch (psi), with a burst pressure of greater than 4000 psi. The battery assembly dimensions are approximately 33 cm x 61 cm x 61 cm, with a mass of 86 kg each. The batteries are located on the zenith deck.

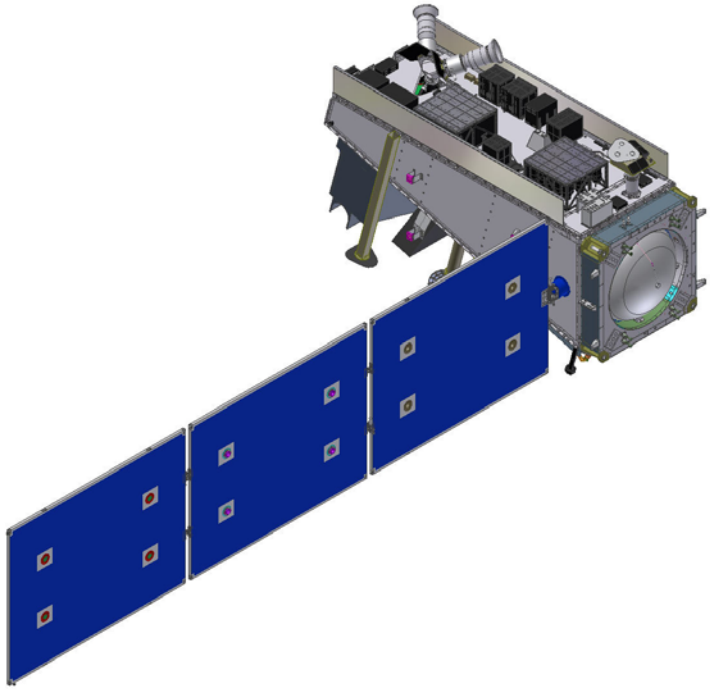

Figure 2-1a. Two views of the NPP Spacecraft

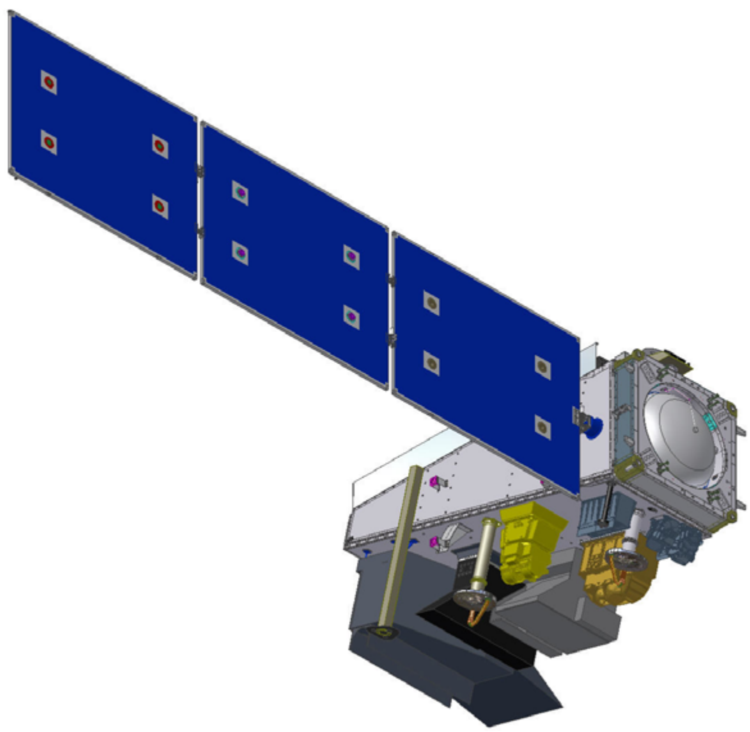

Figure 2-1b. Two views of the NPP Spacecraft

2.1.5 Description of On-Board Propellants

NPP carries a hydrazine (N_2H_4) monopropellant blowdown propulsion system. The propellant is contained in a 40-inch diameter spheroid tank composed of titanium. The tank, tank support structure, thrusters, and associated hardware are attached to the propulsion deck. Nominal beginning of life pressure is 400 psi, provided by nitrogen pressurant. The fuel load is currently expected to be approximately 305 kg.

2.1.6 Description and Location of Fuel Storage and Transport Systems

The NPP fuel storage and transport system is shown in the simplified block diagram in Figure 2-2. The propellant tank is located just inside the deck that faces the anti-velocity direction.

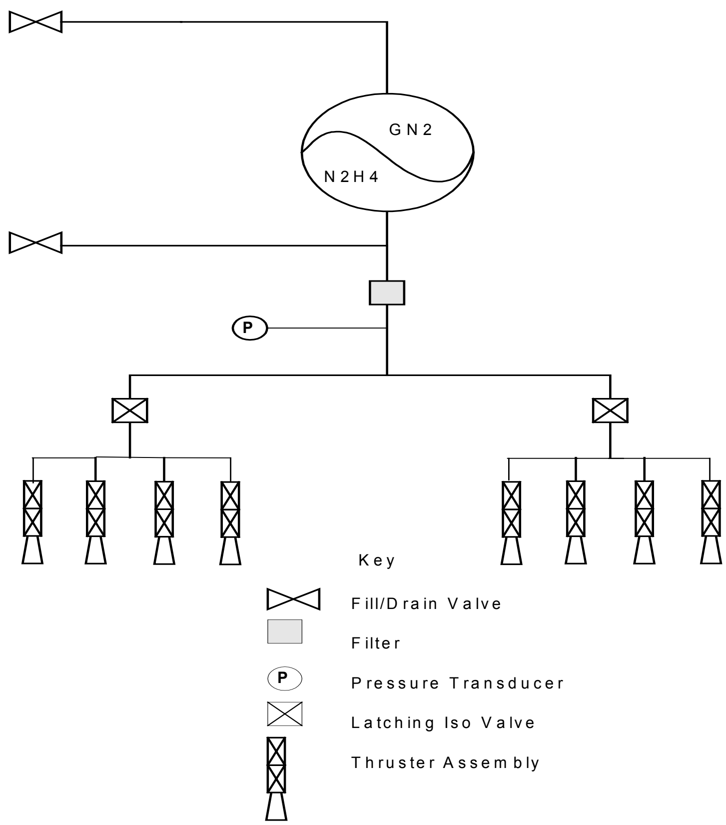

Figure 2-2. Propulsion system block diagram

2.1.7 Description of Range Safety Systems

The NPP spacecraft is not equipped with range safety systems.

2.1.8 Description of Systems Containing Kinetic Energy

The NPP spacecraft contains four Ithaco E reaction wheels to provide attitude control torques. The wheel assemblies are approximately 40 cm in diameter and 17 cm high. The wheel outer shell is made of aluminum that covers a titanium flywheel. Their mass is 12 kg each, with maximum momentum capability of 50 Nms.

All four of the NPP payloads have rotating components. The momentum of these components is not definitely known at this time, but will be probably be less than 1 Nms each. The net momentum into the spacecraft by all payloads is less than 5 Nms.

2.2 Mission Parameters

2.2.1 Number of Spacecraft

The NPP mission consists of a single spacecraft.

2.2.2 Launch Date and Time

NPP is scheduled for launch in October of 2006. Launch will be via a Delta-II launch vehicle from Vandenberg Air Force Base. The launch time will be approximately 10:15 AM (local), to attain the sun synchronous orbit with the required 10:30 AM descending node.

2.2.3 Mission Orbit

NPP will fly in a circular orbit at an altitude of 824 km. The orbit will be sun synchronous (i=98.7 deg), with a 10:30 AM descending node. The on-board thrusters will be used to control the orbit ground track to repeat every 16 days to within 20 km.

2.2.4 Flight Attitude

The spacecraft will fly with the nadir deck towards the earth. The roll, and yaw angles will remain constant. The spacecraft will be pitched at orbit rate to maintain nadir deck earth pointing. The solar array will be pitched to maximize power generation.

3.0 ASSESSMENT OF DEBRIS RELEASED DURING NORMAL OPERATIONS

3.1 Debris Released During Staging, Payload Separation, or Payload Deployment

NPP will not release any debris during staging or payload deployment.

3.2 Debris Released During Mission Operations

NPP will not release any debris during mission operations.

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4.0 ASSESSMENT OF ORBITAL DEBRIS GENERATED BY EXPLOSIONS AND INTENTIONAL BREAKUPS

4.1 Explosions from On-Board Stored Energy

NSS 1740 guideline 4-1 states:

“Limiting the risk to other space systems from accidental explosions during mission: In developing the design of a spacecraft or upper stage, each program, via failure mode and effects analyses or equivalent analyses, will demonstrate either that there is no credible failure mode for accidental explosion, or if there are such credible failure modes, will limit through design or operational procedures the probability of the occurrence of such failure modes. Note: As a quantitative reference, when the probability of accidental explosion can be estimated to less than 0.0001, the intent of the guideline has been met.”

The NPP Observatory carries only two on-board systems, the propulsion system and the battery, which are susceptible to on-board explosions. Overheating, over-pressurization or impact could cause explosion of these systems. The probability of overheating or over-pressurization of these systems is minimal due to built-in robustness, redundancy, and thermal control. For example, the nominal operating pressure of the battery is approximately 1000 psi, whereas the burst strength is greater than 4000 psi. Based on Propulsion System and Electrical Power system Fault Tree Analysis performed by the spacecraft supplier (BATC), it has been determined that there are no credible single point internal failure modes which would lead to an explosion. (Propulsion system or battery explosions due to NPP collision with large and small orbital debris are treated in Section 5.)

As controlled deorbit and therefore electrical power will be required throughout the de-orbit sequence, depletion of stored energy sources at the end of the mission is not applicable to the NPP mission.

4.2 Intentional Breakups

NPP will not undergo intentional breakup or fragmentation.

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5.0 ASSESSMENT OF DEBRIS GENERATED BY ON-ORBIT COLLISIONS

The NPP Observatory has been analyzed to determine the probabilities of on-orbit collisions due to orbital debris or micrometeoroids. The analysis considered both the probability of such collisions for the spacecraft in general and for collisions that would result in loss of ability to support controlled reentry per assessment guidelines 5-1 and 5-2 as follows:

> NSS 1740 guideline 5-1 states: "In developing the design and mission profile for a spacecraft or upper stage, a program should estimate and evaluate the probability of collision with another large object during mission operations. Note: As a quantitative reference, when the probability of collision with large objects is on the order of or less than 0.001, the intent of the guideline has been met." Note that the DAS software defines large debris as items larger than 10 cm (default value). This is about the limit of objects, which can be tracked and catalogued by the United States Space Command. In LEO, the threshold size for cataloguing is approximately 10 to 20 cm in diameter.
>
> NSS 1740 guideline 5-2 states: "In developing the design and mission profile for a spacecraft or upper stage, a program should estimate and evaluate the probability of collision with small debris of sufficient size to cause loss of control to prevent post-mission disposal. Note: As a quantitative reference, when the probability of collision with debris leading to loss of control or inability to conduct post-mission disposal in on the order of 0.01 or less, the intent of the guideline has been met." Small debris is debris sizes less than 1 cm. This is much smaller than those of sufficient size to be tracked and catalogued by the United States Space Command.

For the large debris collision analysis, the maximum nominal surface area exposed to the velocity direction was used ($5m^2 + 4.4m^2 + 13.7m^2$) or approximately.

In the small debris collision analysis, the propellant tank and an individual battery cell were subjected to special consideration as they are the only two items for which a single point failure (i.e. explosion), could cause loss of ability to perform the controlled reentry. Other components needed for controlled reentry were not considered separately for at least one of the following reasons:

- The item is an electronic or sensor component, which would not explode upon collision. All boxes and sensors are redundant.
- The item is internally mounted within the spacecraft and as such thoroughly shielded.
- The item is either internally or externally functionally redundant.

In considering the battery and propellant tank, the area used in the probability of collision calculation reflected:

- For the battery, only the area of a single cell was considered. The batteries are mounted on the zenith face of the spacecraft. The batteries are shielded on the zenith face by the battery panel and on the nadir face by spacecraft structure. Though the sides of the batteries are exposed, the aft-most battery is practically shielded in the velocity direction by other components including the other (fore mounted) battery. This fore mounted battery is in turn partially shielded by other components. The NPP battery mounting locations can be seen in the top view of Figure 2-1a (largest square objects in view).

- For the propellant tank only the exposed area of the tank was considered. As the propellant tank is located at the aft end of spacecraft, most of the tank is shielded by spacecraft structure. (The exposed portion of the spherical propellant tank can be seen from both views of Figure 2-1.)
- In both cases it was assumed that a single penetration would cause an explosion. (As the probabilities of collision were shown to meet the guidelines, further analysis in this area was not conducted.)
- Note the analysis did not consider that the battery as well as the exposed areas of the propellant tank and propellant deck are covered with thermal blankets. These thermal blankets have two internal layers of beta cloth for additional debris impact resistance.

The results of these analyses are summarized in Table 5-1 and were obtained using DAS. In all cases the guidelines have been met for the 5-year mission.

Table 5-1. NPP Orbital Debris Collision Impact Assessment Summary

	Area (m^2)	Particle size (cm)	Total Probability of 1 or more collisions*	Guideline Probability
Full Spacecraft	23.0	10.0	$8.6*10^{-3}$	0.001
Exposed Propellant Tank	1.36	10.0	$5.0*10^{-5}$	0.001
Exposed Propellant Tank	1.36	1.0	$8.0*10^{-4}$	0.01
Exposed Propellant Tank	1.36	0.5	$5.7*10^{-3}$	0.01
Single Battery Cell	0.18	10.0	$6.7*10^{-6}$	0.001
Single Battery Cell	0.18	1.0	$1.1*10^{-4}$	0.01
Single Battery Cell	0.18	0.5	$7.5*10^{-4}$	0.01
* Total includes combined probability of collision from man-made and meteoroid				

6.0 DESCRIPTION OF POST-MISSION DISPOSAL PROCEDURES AND SYSTEMS

NSS 1740 guideline 6-1 states:

"A spacecraft or upper stage with perigee altitude below 2000 km in its final mission orbit will be disposed of by one of three methods:

> Atmospheric reentry option: Leave the structure in an orbit which, using conservative projections for solar activity, atmospheric drag will limit the lifetime to no longer that 25 years after completion of mission.
>
> Maneuvering to a storage orbit between LEO and GEO: maneuver to an orbit with perigee altitude above 2500 km and apogee altitude below 35,288 km (500 km below GEO altitude).
>
> Direct retrieval: Retrieve the structure and remove if from orbit within 10 years after completion of the mission."

Of these, only the atmospheric reentry option is realistic for NPP.

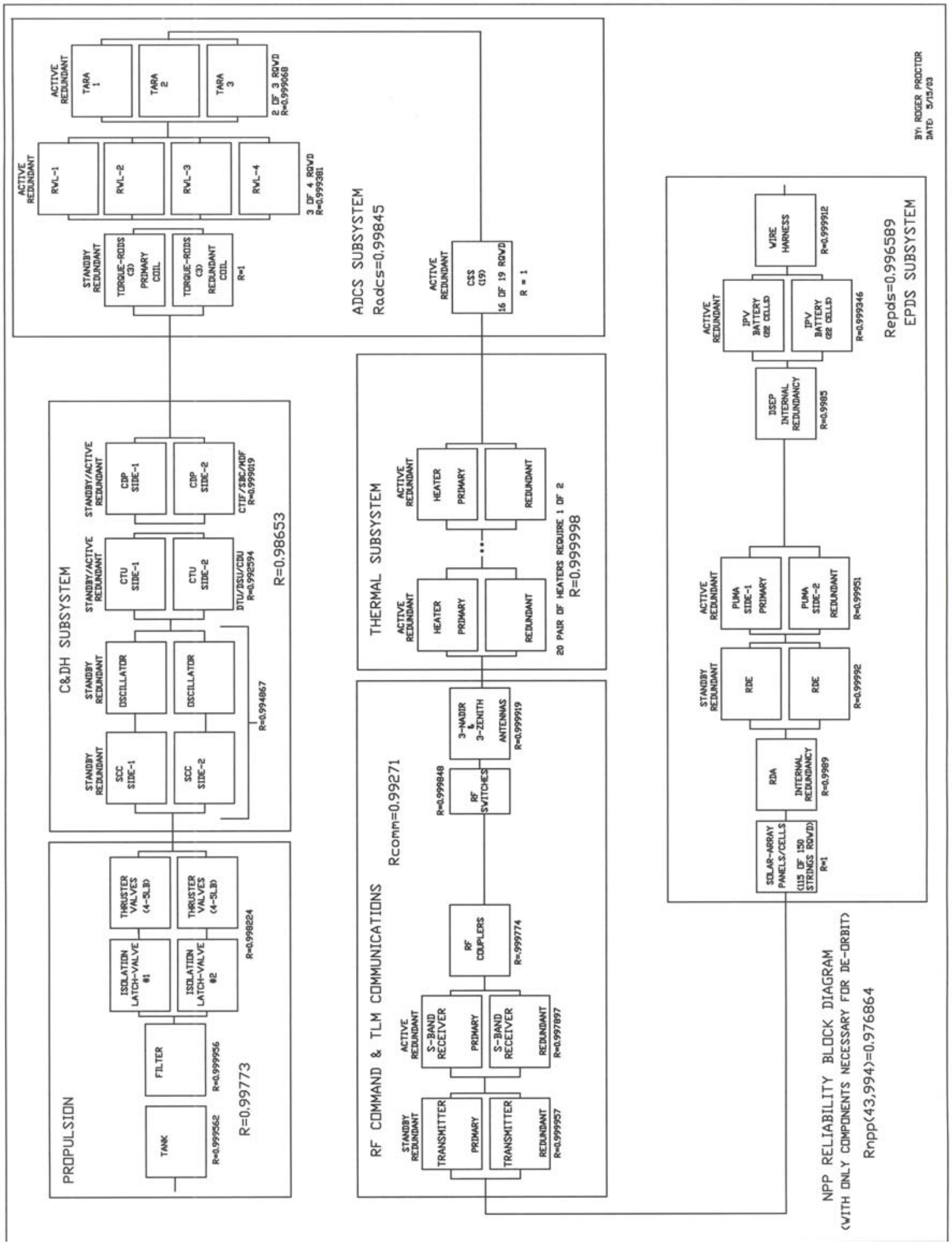
6.1 Planned Option for Post-mission Disposal

Controlled de-orbit is currently planned for the post-mission disposal of NPP. This will meet the guideline 6-1. Controlled de-orbit was selected due to the high casualty risk associated with an uncontrolled reentry as documented in Section 7.0.

6.1.1 Description of Disposal Procedures and Systems

Described in this section are the hardware and concept of operations for performing controlled de-orbit for NPP. Figure 6-1 identifies the components for each subsystem required to perform the baseline controlled reentry maneuvers.

Figure 6-1. NPP Baseline Components / Reliability For Controlled Reentry



Check the NPP CCR website at http://nppcm.gsfc.nasa.gov/ccr/npp to verify that this Is the correct version prior to use.

6.1.2 Hardware For Performing Controlled Reentry

Fuel Tank Size. To meet the controlled reentry requirement, the fuel tank proposed for the NPP spacecraft is the 40 x 28” spheriod. The selection of qualified tanks is very limited; this was judged to be the optimal of those available. To perform controlled reentry, this tank will be loaded with 305 kg of fuel, which will produce 300 m/s of delta-v for the 2200 kg NPP spacecraft. This will provide a fuel margin of 15% for the mission operations and 10% for de-orbit.

Thruster Size. The standard BCP 2000 bus is equipped 4 1-lb thrusters for performing orbit changing maneuvers. Performing controlled reentry will require larger thrusters because the final burn to cause reentry must be larger than the current propulsion system can produce. This burn must be approximately 30 m/s, to lower perigee from approximately 150 km to 50 km. The standard propulsion system was not designed to provide such a large impulse.

To enable controlled reentry, the thruster set for the NPP spacecraft will be eight 5-lb thrusters in four redundant pairs. During the controlled reentry burns, four thrusters will be off-pulsing to maintain attitude control.

Thermal Design. To be capable of controlled reentry, the NPP spacecraft must be capable of performing long burns. An earlier version of this spacecraft bus performed ten-minute long burns for the QuikSCAT orbit raising campaign. The NPP controlled reentry will involve about 10 ten-minute long burns, and well as a final burn of approximately 20 minutes duration. The spacecraft thermal system is designed to accommodate these long burns.

Burn Length. The proposed burns to lower perigee are sufficiently long that the inefficiencies due to their finite duration must be accounted for. A Matlab program was used to determine the efficiency of long burns. This program divided the maneuver into small segments and calculated the change in orbit elements due to an impulsive maneuver applied at each time. Efficiency is defined in this context in two ways: as the amount of actual perigee change produced by the burn as compared to an impulsive (instantaneous) burn, and as the amount of (unwanted) apogee change.

Figure 6-1 shows the burn inefficiencies as a function of burn length using a 5 lb thruster. For 10 minute long burns, both types of inefficiency are less than 1%. For 30 minute long burns, the inefficiencies total nearly 16%. These inefficiencies must be accounted for in the design of long burns, particularly the last burn, which will be 20-30 minutes in duration.

6.1.3 Concept of Operations

Controlled de-orbit will require most of the fuel. At the start of the de-orbit, only about 55 m/s of the available 300 m/s of delta-v will have been expended.

A series of 9 ten-minute long burns will be performed at apogee to lower perigee. These burns will be performed in clusters of 3, two orbits apart. This allows time for the thrusters to cool between burns, and for the operations team to evaluate performance.

A cluster will be performed every two days. This allows time for orbit determination, thruster calibration, and planning the next cluster. This series of burns will lower perigee from 824 km to approximately 200 km. The delta-v realized from each of these burns will vary due to the decrease in tank pressure, as shown in Figure 6-2.

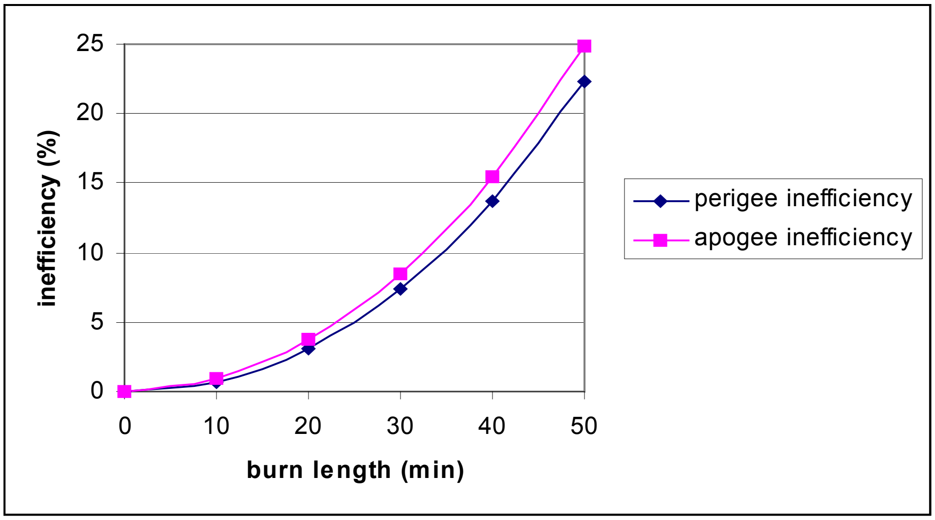


Figure 6-2. Inefficiencies due to long burn duration

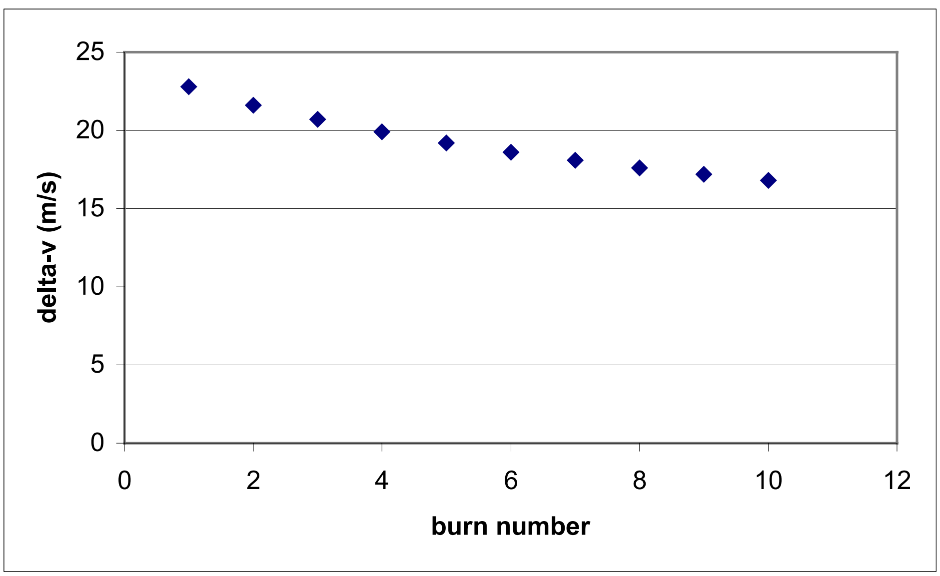


Figure 6-3. Delta-v from the 9 ten-minute perigee lowering burns

The last two burns must be performed one orbit apart. The second to last burn will be another ten-minute long burn, which will lower perigee to 150 km. Spacecraft lifetime in this orbit is 3 to 4 days.

The last burn will be performed one orbit after the next to last, to reduce the chance of uncontrolled reentry. This burn will reduce the perigee altitude from 150 to 50 km. The spacecraft will break up due to drag during the next perigee passage.

The last burn will be approximately 19.4 minutes long. To change perigee from 150 to 50 km will require 29.4 m/s. Due to inefficiencies because of the significant burn duration (see Figure 6-1), the burn must produce more than 29.4 m/s of delta-v. The tank pressure at the start of this burn will be about 180 psi, so the thrust will be significantly less than at the start of the mission. The perigee-lowering inefficiency for a 30 minute burn (Figure 6-1) is about 7.5%, so the delta-v of this burn must be 1.075*29.4 m/s = 31.6 m/s. By scaling off a curve of total delta-v versus time, this burn will take about 19.4 minutes. This is significantly shorter than the maximum practical burn duration. Inefficiencies due to burn length get much larger for longer burns, as shown in Figure 6-1. The final de-orbit burn for the Compton Gamma Ray Observatory was also 30 minutes in length.

6.1.4 Identification of Obstacles to Successful Post-mission Disposal

Controlled reentry of the NPP spacecraft would be compromised or prevented if a critical spacecraft subsystem failed. This is largely mitigated by redundancy, although by the end of the mission one or more subsystems may be using redundant components due to failure of the primary units. Possible failure scenarios include:

- Failure of the spacecraft control computer (both primary and redundant).
- Failure of both primary and redundant sides of the ADCS, C&DH, RF/Communication, Propulsion, or EPDS subsystems.
- Incapacitating impact by orbital debris. The propellant tank and battery are the most vulnerable components as described in Section 5.0 above.
- The calculated reliability for controlled reentry is 0.98. That is believed to meet the intent of the NASA guideline (0.99). Additional hardware to achieve complete compliance was deemed impractical.

6.2 Post-mission Lifetimes Without Controlled Reentry

Post-mission lifetimes were calculated to determine what disposal measures would be necessary if controlled de-orbit is not used. Orbital lifetimes of NPP were calculated using the DAS software. The following inputs to DAS were used:

- Apogee and perigee altitude = 824 km
- Spacecraft area = 23 m^2
- Area to mass ratio = 0.012

The spacecraft area was taken as ¼ of the sum of the body surfaces (approximately 2*10m^2 +2*5m^2 +4.4m^2 +2.9m^2) and both sides of the solar array area (13.75 m^2) for a total area of 16m^2, as per the debris guidelines (NSS 1740, p. 5-2). The post-mission spacecraft mass will be about 1900 kg.

The DAS software indicates that the orbital lifetime for NPP if released at 824 km altitude is approximately 300 years. This clearly does not satisfy the guideline; post-mission orbit lowering is required. Additional DAS runs indicate that the altitude would have to be reduced to 615 km to meet the 25-year post-mission lifetime requirement. This would require 110 m/s of delta-v. Post-mission disposal by orbit-lowering would require the ability to perform post-mission passivation.

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7.0 ASSESSMENT OF SPACECRAFT REENTRY OPTIONS

7.1 Proposed Changes to the NASA Safety Standard

Prior to reviewing the results of the ORSAT analysis it is important to understand two changes to the NASA Safety Standard currently being considered. Both of these changes are presumed to have wide backing and formal adoption of the changes is expected in the coming year:

- **Casualty Threshold:** The current NASA Safety Standard allows for uncontrolled reentry for those spacecraft choosing the atmospheric reentry option provided that the associated total Debris Casualty Area (DCA) is less than 8 m^2. Otherwise a controlled reentry is called for. While the casualty risk standard was always 1 in 10,000, the guideline as written did not account for increased casualty risk as the population expands, nor did it differentiate the associated risks due to orbit inclination. To remedy this, a human casualty threshold of 1 in 10,000 (1 casualty per 10,000 reentry events) has been proposed and is now widely used. The impact of this guideline change on allowable DCA as a function of year of reentry and orbital inclination is shown in the following table. The 28.5° was chosen to show the difference between spacecraft orbits whose ground track spends a relatively high percent of the time over populated areas in comparison to spacecraft in polar orbits such as NPP.

Table 7-1. Allowable DCA To Meet 1: 10,000 Threshold

	Allowable DCA (m^2) to Meet 1:10,000 Threshold	
Orbital Inclination (°)	**2012 Year of Reentry**	**2037 Year of Reentry**
98.7°	9.6	8.0
28.5°	5.4	4.3

- **Kinetic Energy At Impact**: Under current Safety Standard guidelines no differentiation is made between the casualty risks associated with debris surviving with high and low kinetic energies. Based on studies by other U.S. Government agencies, a generally accepted threshold of 15 J has been identified for debris that could result in human casualty. While not officially adopted as part of the Safety Standard, this threshold has wide backing and formal acceptance is expected in the coming year.

7.2 Estimate of DCA for Debris Surviving Uncontrolled Reentry

In conjunction with the Johnson Space Center Orbital Debris Program Office, the NPP Project has undertaken a reentry survivability analysis using the JSC tool ORSAT. The analysis incorporated all spacecraft and instrument components and used ORSAT. A complete summary of the characteristics of the components modeled as well as the results of the analysis are documented in the NPP ORSAT report generated by JSC (see Appendix A). Table 7-2 summarizes the components identified as survivors from that analysis. From the table it can be seen that the total DCA with and without the kinetic energy threshold applied are 38.0 m2 and 1774.6 m^2 respectively. Of the 1774.6

m^2 DCA in the no threshold case over $1722.6m^2$ results from extremely low impact solar array debris.

7.3 NPP Reentry Debris Risk Calculation

NPP casualty risks have been calculated for various years of reentry as summarized in Table 7-2. These results were generated using the data shown in Table 7-3. As mentioned above (Section 6.2), NPP would have to use varying amounts of propulsive capability to meet these years of reentry. From the table it can be seen that under no circumstances can NPP conform to the 1 in 10,000 standard.

Table 7-2. NPP Casualty Risk as a Function of Year of Reentry

Year of reentry	Casualty Risk (15 J KE threshold)	Casualty Risk (no KE threshold)
2012	1:2,527	1: 54
2022	1: 2,328	1: 50
2032	1: 2,171	1: 46
2037	1: 2,109	1: 45

Table 7-3. NPP ORSAT Summary of Debris Surviving Uncontrolled Reentry

#	Object Name	Material	Downrange (km)	Impact BC (kg/m^2)	Max. Demise Factor (%)	Debris Casualty Area (m^2)	Impact Mass (kg)	Impact Kinetic Energy (J)
1.1	Solar Cells	GaAs	209	2.8	95	1722.63	16.1	0.09
2.0	**Main Deployment Hinge**	**Titanium**	**911**	**152.6**	**92**	**1.06**	**2.4**	**1485**
7.0	Star Tracker Flexures	Titanium	325	4.9	96	2.59	0.1	1
31.1	**RWA Rotors**	**Titanium**	**774**	**128.4**	**47**	**3.36**	**25.2**	**6515**
39.0	**PM Corner Post Fitting**	**Titanium**	**970**	**99.0**	**92**	**2.54**	**12.3**	**2450**
40.0	**Propellant Tank**	**Titanium**	**716**	**91.6**	**52**	**2.31**	**34.0**	**25000**
74.0	**Frame (S-7)**	**AlBeMet**	**760**	**79.0**	**86**	**1.15**	**15.2**	**9639**
75.0	**Bench, Optical (S-6)**	**Beryllium**	**652**	**45.9**	**48**	**0.98**	**3.4**	**1253**
76.0	**Housing, mirror - telescope**	**Beryllium**	**880**	**139.5**	**78**	**0.63**	**5.1**	**5733**
77.0	**Interferometer Housing**	**Beryllium**	**690**	**60.9**	**59**	**0.77**	**4.2**	**2049**
82.1	**SP board stiffener**	**Beryllium**	**453**	**9.2**	**22**	**2.07**	**0.7**	**18**
82.2	SP board stiffener	Beryllium	411	6.5	23	2.07	**0.5**	9
82.3	**FW board stiffener**	**Beryllium**	**494**	**12.5**	**41**	**1.18**	**0.5**	**17**
92.0	**Earthshield**	**AlBeMet**	**372**	**9.7**	**62**	**0.96**	**1.2**	**97**
93.0	**Patch housing**	**Beryllium**	**470**	**18.3**	**84**	**0.56**	**0.3**	**49**
94.0	**Adapter ring**	**Beryllium**	**367**	**9.5**	**66**	**0.80**	**0.4**	**30**
95.0	Patch emitter	Beryllium	322	7.0	73	0.65	0.1	8
96.0	Sub-patch housing	Beryllium	389	7.6	95	0.46	0.0	2
97.0	**Vac housing**	**AlBeMet**	**507**	**23.0**	**71**	**0.73**	**1.2**	**218**
98.0	**Radiator housing**	**AlBeMet**	**394**	**12.2**	**83**	**0.60**	**0.3**	**29**
99.0	**Vac housing rear cover**	**AlBeMet**	**478**	**17.1**	**78**	**0.61**	**0.3**	**36**
100.0	Radiator emitter	AlBeMet	281	4.9	74	0.71	0.1	5
101.0	**Scene Select Module (SSM)**	**AlBeMet**	**448**	**16.4**	**63**	**0.85**	**1.4**	**178**
102.0	SSM Scan Mirror	Beryllium	246	3.9	67	0.79	0.2	5

#	Object Name	Material	Downrange (km)	Impact BC (kg/m^2)	Max. Demise Factor (%)	Debris Casualty Area (m^2)	Impact Mass (kg)	Impact Kinetic Energy (J)
103.0	**Optics Module Mainframe**	**Al / Ti**	**401**	**4.2**	**87**	**2.86**	**4.6**	**155**
113.0	**Half Angle Mirror**	**Beryllium**	**521**	**23.8**	**92**	**0.49**	**0.1**	**21**
121.0	**Kinematic Mounts**	**Titanium**	**689**	**42.7**	**93**	**1.39**	**0.6**	**74**
123.0	**Electronics Module**	**Aluminum**	**753**	**33.7**	**94**	**1.90**	**16.5**	**4400**
131.0	Antenna Structure	Gr / Al / Cu	157	1.7	88	1.31	0.5	6
142.0	Receiver V-shelf	Al / Ti	409	2.6	98	0.74	0.2	3
143.0	Receiver W-shelf	Al / Ti	378	9.0	89	0.56	0.2	13
144.0	Reflector, Small, ATMS	Beryllium	392	11.2	79	0.57	0.1	12
145.0	**Reflector, Large, ATMS**	**Beryllium**	**363**	**9.2**	**68**	**0.71**	**0.3**	**20**
146.0	**Baseplate, ATMS**	**Beryllium**	**520**	**26.2**	**66**	**0.72**	**1.4**	**297**
147.0	**Baseplate Cover, ATMS**	**Beryllium**	**498**	**20.6**	**66**	**0.65**	**0.4**	**71**
149.0	1 SP Resolver Rotor	Titanium	472	8.1	98	0.89	0.1	3
152.0	**Telescope Housing**	**Titanium**	**837**	**112.4**	**52**	**0.68**	**5.6**	**5000**
153.1	**Motor**	**Titanium**	**843**	**125.5**	**88**	**0.45**	**0.6**	**576**
153.2	**Radiation Shield**	**Titanium**	**779**	**82.8**	**72**	**0.47**	**0.5**	**351**
153.3	Calibration Wheel	Titanium	533	7.4	73	0.60	0.2	12
153.4	Cal Wheel Cover	Titanium	458	2.7	69	0.67	0.1	2
156.0	**Spectrometer Housing**	**Titanium**	**711**	**62.4**	**69**	**0.87**	**6.9**	**3450**
157.0	**Profiler Assembly**	**Titanium**	**895**	**129.4**	**85**	**0.54**	**2.3**	**2362**
159.0	**Telescope Housing**	**Titanium**	**729**	**68.8**	**78**	**0.67**	**3.2**	**1740**
163.0	**VIIRS Elec Module (EM) Support**	**Titanium**	**752**	**74.0**	**61**	**1.37**	**11.8**	**7000**
168.0	**Fitting, MDH, Inner**	**Titanium**	**518**	**28.9**	**77**	**1.60**	**1.1**	**88**
170.0	**IPH Assy - Powered (1/2)**	**Titanium**	**607**	**28.9**	**95**	**1.46**	**0.7**	**54**
171.0	IIPH Assy - Floating (1/2)	Titanium	523	13.1	96	1.34	0.2	6

Note: Objects in boldface type exceed the 15-J lethality limit.

Total > 15 J = **37.98 164.9**
Total = 1774.56 185.0

Check the NPP CCR website at http://nppcm.gsfc.nasa.gov/ccr/npp to verify that this Is the correct version prior to use.

8.0 ACRONYM LIST

ADCS	Attitude Determination and Control Subsystem
A.hr	Ampere Hours
ATMS	Advanced Technology Microwave Sounder
BATC	Ball Aerospace and Technology Corporation
BC	Ballistic Coefficient
BCP	Ball Commercial Programs
C&DH	Command and Data Handling
Cm	Centermeter
CrIS	Cross-Track Infrared Sounder
DAS	Debris Analysis Software
DCA	Debris Casualty Area
EPDS	Electrical Power Distribution System
EOS	Earth Observing System
GEO	Geosynchronous Earth Orbit
GSFC	Goddard Space Flight Center
IPO	Integrated Program Office
J	Joules
JSC	Johnson Space Center
Kg	Kilogram
lb	Pound
LEO	Low Earth Orbit
MLI	Multi-Layer Insulation
N_2H_4	Hydrazine
NASA	National Aeronautics and Space Administration
NiH	Nickel Hydrogen
Nms	Newton-Meter-Second

NPOESS	National Polar-Orbiting Operational Environmental Satellite System
NPP	NPOESS Preparatory Project
NSS	NASA Safety Standard
OMPS	Ozone Mapping and Profiling System
ORSAT	Object Reentry Survivability Analysis Tool
Ps	Probability of Success
Psi	Pounds per Square Inch
RF	Radio Frequency
RSDO	Rapid Spacecraft Development Office
VIIRS	Visible-Infrared Imager Radiometer Suite